Microcontroller Based Novel Dc-to-Ac Grid Connected Inverter Topology

Adil Sarwar[1], M.S. Jamil Asghar[2] and Farhad I. Bakhsh[3]
[1, 2, 3] Department of Electrical Engineering, Aligarh Muslim University, Aligarh, India
Email[1]: adilsarwar123@gmail.com

***Abstract*— The conventional line commutated ac-to-dc converters/ inverters have square-shaped line current which contains higher-order harmonics. Moreover, it requires a costly and bulky dc inductor or choke. The line current with the high harmonic contents generates EMI and therefore it causes more heating of the core of distribution or power transformers. Alternatively, PWM based inverters using MOSFET/IGBT switches can be used for the above purpose. However, apart from higher switching losses, the power handling capability and reliability of these devices are quite low in comparison to thyristors/ SCR. A thyristor based forced commutated inverters are not suitable for PWM applications due to the problems of commutation circuits. A pure sinusoidal voltage output or waveform with low harmonic contents is most desirable in the conversion from dc to ac. In the present work, a novel two pulse line commutated inverter is been proposed with control signal generated from PIC 16F 877A. It improves the wave shape hence it reduces the total harmonic distortion (THD) of the grid interactive-inverter. The simulation of the circuit is done using SIMULINK. Moreover, the performance of the proposed circuitry is far better than the conventional line-commutated inverter. It reduces THD, number of thyristors and dispenses with the bulky dc inductor/ choke. A prototype model is developed for discontinuous line current mode. The results are also compared with the simulation results in SIMULINK/ MATLAB.**

***Index Terms*—grid connected inverter, total harmonic distortion (THD), simulink, line current**

I. Introduction

Power electronic converters and controllers are extensively used for different types of domestic, agricultural and industrial applications. Ac-to-dc converters are widely used for the dc voltage and power control e.g. charging of batteries in inverters, UPS, cell-phones and speed control of dc motors etc. [1-2]. A conventional thyristor or power semiconductor device based ac-to-dc converter, with a dc source and an inductor or highly inductive load at the load side, operates in inversion mode when the switching angle exceeds 90^{o}, known as grid-connected inverter [3-7]. Thus power flow takes place from dc source to ac grid. These ac-to-dc converters are also called controlled rectifiers. The average power flow through them is unidirectional as well as bi-directional.

However, the conventional thyristor based converters or rectifiers introduce substantial higher-order harmonics in the line current. This is the main drawback of these converters. Due to an inductor at the load side, there is very small ripple in the load current (dc side) and it has almost constant magnitude. Therefore, the line current (ac side) has square shape and the total harmonic distortion (THD) is very high. It causes electromagnetic interference (EMI) to the neighboring communication networks, computer networks or lines (LAN/ WAN) and overheating of the core of distribution transformers. Therefore, in general, due to presence of higher order harmonics in the line current, square wave circuit topology although simple, is not commonly adopted for dc-to-ac power inversion and to feed power tapped from various energy sources to ac grid. Moreover, in this case, the load current is high but its ripple is very small. Therefore, the magnitude of magnetic-field intensity (H) in inductor remains high (with small variation due to small current ripple). As the load current (hence H) does not go back to zero level, therefore, no resetting of core takes place and the core offers very low effective inductance. Thus a bulky inductor is required at the load or dc side. It increases the cost, size and weight of the conventional dc-to-ac inverter.

In this paper the discontinuous phase control switching technique [1], [8] is extended for a novel dc-to-ac Controlled Inverter using a centre-tapped transformer. Instead of one inductor and one dc source at load side or dc side, here two branches are put at load side or dc side, where each branch consists of one inductor and one dc source. The thyristors are triggered or switched using a controller circuit. One thyristor with an inductor and a dc source forms a positive load branch and it is switched in positive-half cycles of ac grid only. Similarly, another thyristor with another inductor and another dc source forms a negative load branch and it is triggered or switched in negative-half cycles of ac grid only. Each load branch is connected between one terminal of the secondary winding and central tapping of the centre-tapped transformer. The dc side load current which flows in each load branch is a half-wave and discontinuous current. Therefore, wide variation of magnetic-field intensity (H) hence flux or flux-density (B) takes place. Therefore, the variations in B and H complete half of the B-H loop. At high value of H, with almost constant magnitude, the slope on B-H is small. The effective inductance also becomes small which is proportional to the slope on B-H curve. Therefore, for a dc load current, the size of inductor increases enormously which increases cost, size, weight and losses in the inductor. Here, since partial reset or reversal of flux in B-H loop takes place due to half-wave dc current of the inductor windings, therefore the effective inductance becomes high. Although the current through the half winding of the secondary side of

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the centre-tapped transformer is discontinuous and its shape is like a half-wave sinusoidal current, but the net line current on the primary side of the centre-tapped transformer or ac grid becomes continuous. Thus, THD of the line current of ac grid becomes very low, contrary to the conventional thyristor based dc-to-ac inverters, where due to constant magnitude load current or dc current, the line current has almost square-shape and THD remains high. Moreover, in this proposed method the effective inductance of the inductor increases thus cost, size, weight and losses in the inductors reduce.

II. Components Of A New Dc-To-Ac Controlled Inverter

The novel dc-to-ac Controlled Inverter comprises of an ac grid, a controller circuit and a pair of thyristors with two inductors, two independent dc sources and a centre-tapped transformer. The controller circuit gives command signals which are in the form of synchronized pulses for the thyristors and ultimately controls the real power flow to the ac grid.

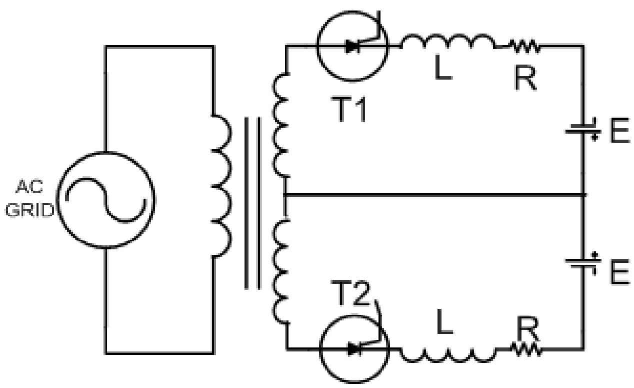

Figure1. A New ac-to-dc Controlled Inverter circuit topology

A full-wave converter circuit with RLE load works in two modes of operation i.e. rectification mode and inverter mode. It works in inversion mode when the switching angle is greater than 90° [1-2], [9]. Here, a new circuit topology is proposed as shown in Figure 1. Although two dc sources or a dc source with center-tap arrangement are needed but it dispenses with a bulky and costly dc inductor. In the proposed circuit, the line current flowing through the inductor is bi-directional (or ac).

When the circuit works in inverter mode, the dc source transfers power to the ac source. The major advantage of the proposed configuration is that in discontinuous mode of operation, the waveform resembles a sinusoidal wave with low harmonic contents. Moreover, the proposed configuration is suitable for solar PV based power generation [10-11].

III. Analysis Of A New Dc-To-Ac Controlled Inverter

In general, the load current can be either continuous or discontinuous. In the case of continuous current operation, the current of both thyristors overlaps. It depends upon load voltage (PV voltage which depends on insulation and temperature), phase angle of load or inductor (ϕ) and the switching angle [1-2], [8-11]. In the case of discontinuous current operation, the waveform of load current depends upon both the switching angle and load circuit parameters. The output waveform of current resembles more of a sine wave.

A) Discontinious Mode

In the positive half cycle the thyristor; T_1 is triggered at an angle 'α'. The conduction diagram of thyristor T_1 is shown in Figure 2. During negative half cycle the thyristor; T_2 is triggered at an angle 'π + α'. The conduction diagram of thyristor T_1 is shown in Figure 3.

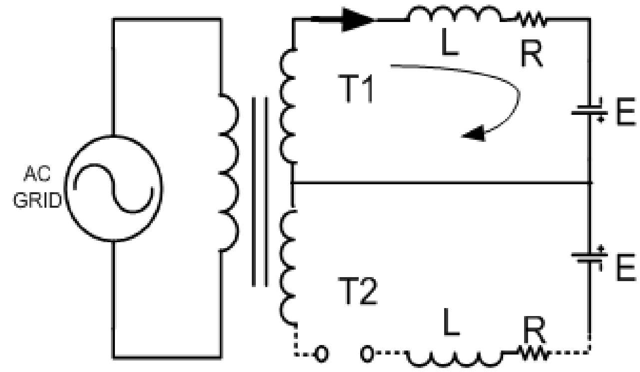

Figure 2. Conduction diagram of the dc-to-ac Controlled Inverter during positive half cycle

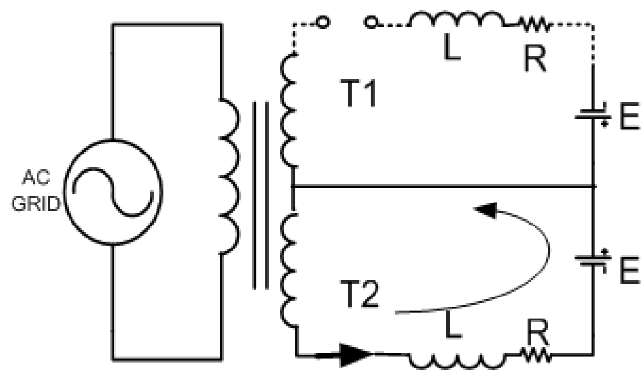

Figure 3. Conduction diagram of the dc-to-ac Controlled Inverter during negative half cycle

The expression of the line current is given by [1]:

$$L \frac{di}{dt} + iR = V_m \cos \omega t + E \qquad (1)$$

For ωt = θ and m = (E/V_m), it gives,

$$I_1 = \cos(\theta-\varphi) + \frac{m}{\cos(\varphi)} * \left(1 - e^{\frac{-(\theta-\alpha)}{\tan(\varphi)}}\right) - \cos(\varphi-\alpha) * e^{\frac{-(\theta-\alpha)}{\tan(\varphi)}} \qquad (2)$$

For conduction of T2 in negative half cycle, the expression of line current is given by:

$$I_2 = -\cos(\theta-\varphi-\pi) - \frac{m}{\cos(\varphi)} * \left(1 - e^{\frac{-(\theta-\alpha-\pi)}{\tan(\varphi)}}\right) + \cos(\varphi-\alpha) * e^{\frac{-(\theta-\alpha-\pi)}{\tan(\varphi)}} \qquad (3)$$

The net line current, ***i*** is equal to $i_1 + i_2$.

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B. Continuous Mode

During continuous conduction mode, the thyristor T2 starts conduction before the commutation of T1. Under this condition a transient condition exists for a short duration. The load current is the sum of currents flowing through the thyristors. Under steady-state condition, the current through load (inductor) resembles a pure sine wave. But the loop currents ($\boldsymbol{i}_1$ and $\boldsymbol{i}_2$) become very high which may even lead to failure of thyristors. Moreover, inductor supplies VAR only and no real power is supplied to the grid.

IV. Simulation Of The Novel Dc-To-Ac Controlled Inverter

A. Simulation Model

Simulink model for proposed topology is shown in Figure 4. Resistance is included in series with the inductor to simulate the real inductor. The value of inductance is 0.05 H. The series resistance is 0.2 ohms. The centre tap transformer has a ratio 230 V :: 150-0-150 V. Triggering pulses are given from pulse generator block set of simulink library. For a practical circuit these pulses need to be synchronized with the grid voltage waveform and pulses should be generated (with delay) at every zero crossing of the grid voltage. The dc battery voltage is varied and reading taken for three different battery voltages (24 V, 36 V, 48 V). For each battery voltage the switching angle is varied from 105 degrees to 165 degrees and THD and power transfer variation for different combination of switching angles as shown in Figure 5 and Figure 6 respectively.

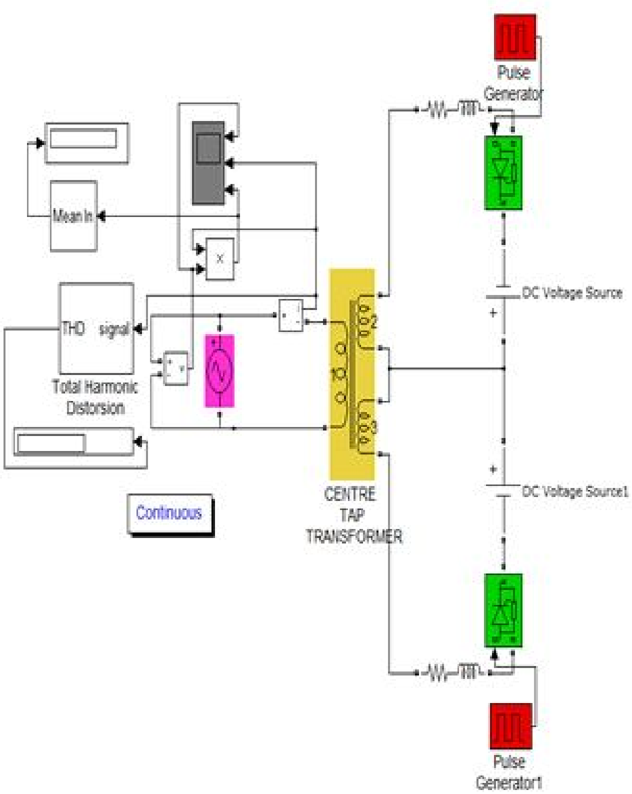

Figure 4. MATLAB Simulation model of A New dc-to-ac Controlled Inverter

B. Simulation Results

The simulation results obtained using simulink model is as shown in Figure 5 and Figure 6.

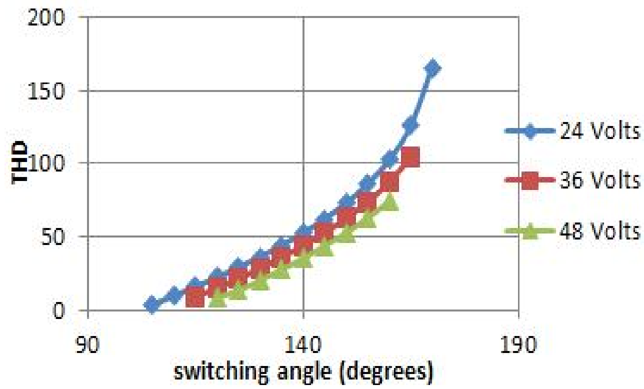

Figure 5. THD of line current versus switching angle

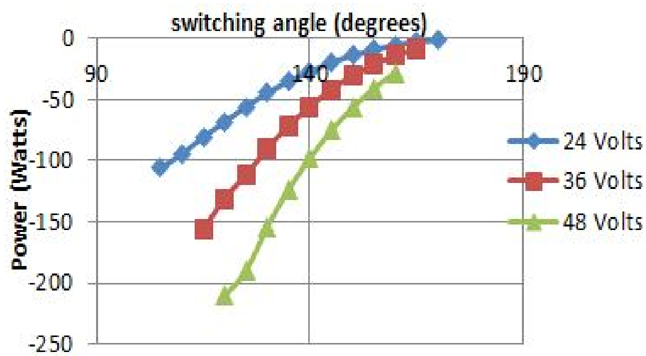

Figure 6. Power transferred to grid versus switching angle

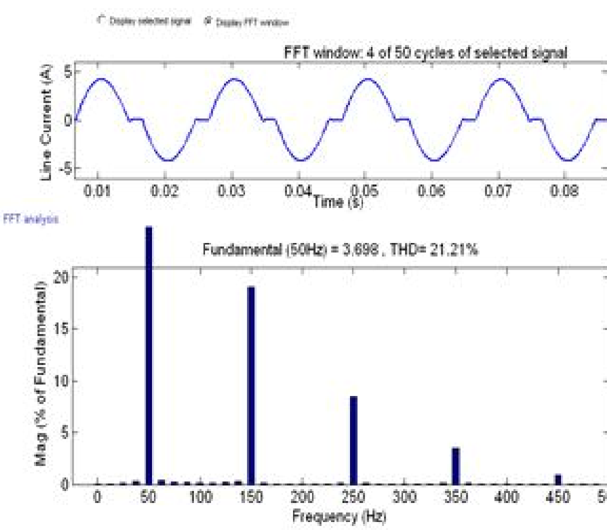

Figure 7. Line current with harmonic contents in Transformer less grid interactive inverter system. Switching angle is 120 degrees and battery voltage is 48 V

Variation of THD shows an increasing trend with increasing switching angle whereas the power transferred to grid decreases with increase of switching angle. Thus, the inverter should be designed to switch at switching angle close to 90 degrees for optimum performance. Figure 7 shows the line current and its harmonics as obtained on power GUI blockset of SIMULINK library.

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V. Experimental Setup And Results

UJT based triggering circuit as shown in Figure 8 is designed to generate synchronized triggering pulses. TYN 612 (Thyristor) is used for the experimental purpose. The battery voltage is 12 V. The centre tapped transformer ratio is 230 V:: 50-0-50 V. Table 1 compares the experimental result with that of simulated result. They are in close proximity.

Table I: Comparison of Experimental and Simulated data

Sl.no.	Firing angle (ms)	Firing angle (degrees)	Power (W) Simulated	Power (W) Practical	THD Practical	THD Simulated
1.	6.8	122	-15.98	-14	19.4	15.16
2.	7.4	133	-11.11	-9	22.6	24.48
3.	8	144	-6.92	-6	39.7	40.06
4.	8.6	155	-3.8	-3	48.3	58.89

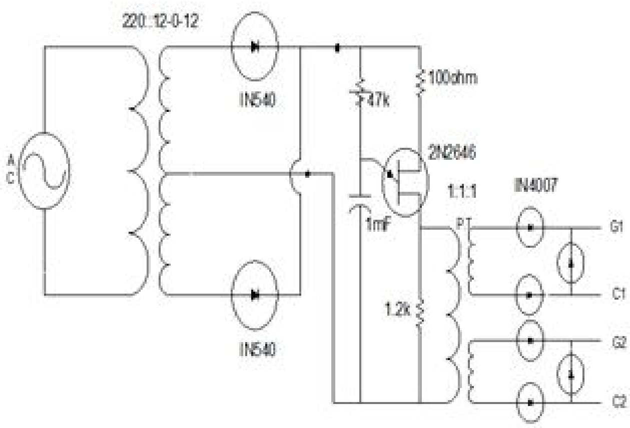
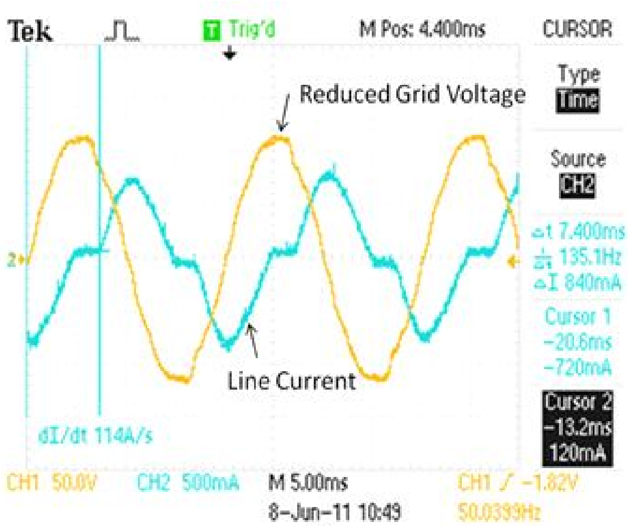
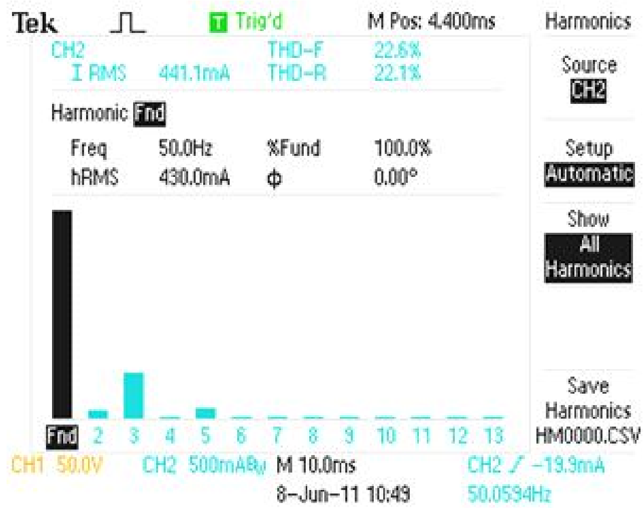


Figure 8. Circuit diagram of the UJT based triggering circuit



(a)

Figure 9 shows the line current with harmonics for switching angle = 133°.



(b)

Figure 9. (a) Blue wave form is the line current (switching angle=133 degree) with reduced grid voltage (red waveform) (b) Harmonics in line current

VI. Microcontroller Based Grid Interactive Inverter

Grid connected inverter has been practically implemented using PIC 16F877A microcontroller. Figure 10 shows the microcontroller based implementation of above topology. Switching pulses for the thyristors at the desired delay angle have been generated from PIC 16F877A microcontroller. These pulses are shown in Figure 11. These pulses are given to driver circuit shown in figure. From the driver circuit, the switching pulses are given to thyristors. The flowchart for generating synchronized pulses for triggering the thyristor has been shown in Figure 13. The complete experimental setup is shown in Figure 12.

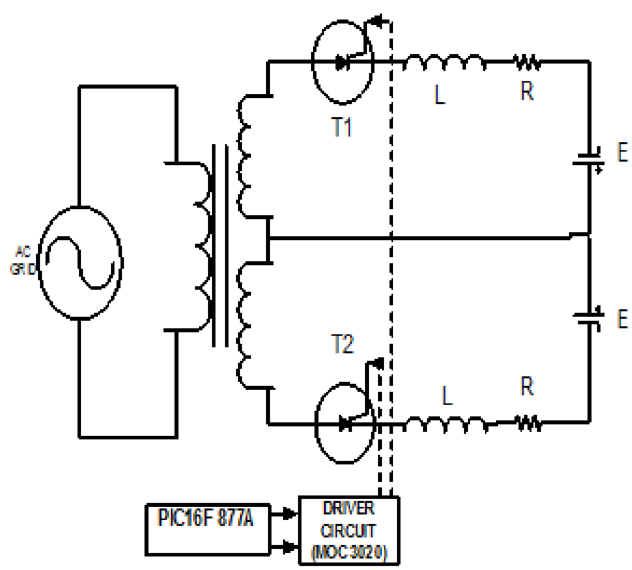


Figure 10. Microcontroller based implementation of grid interactive inverter

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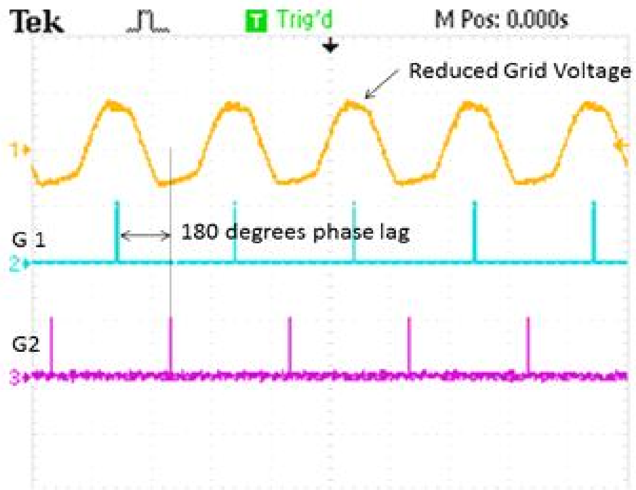

Figure 11. Synchronised pusles for thyristors

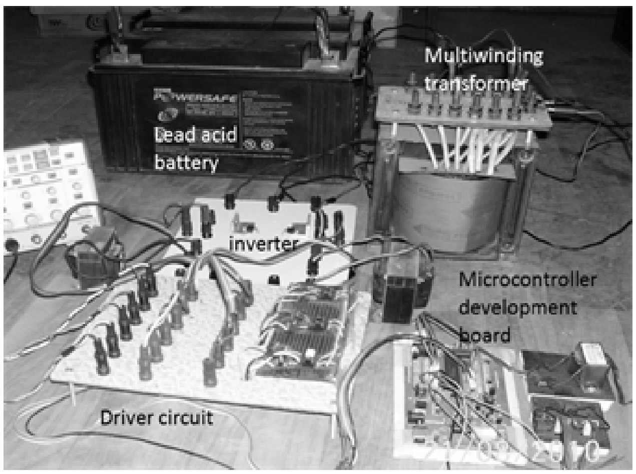

Figure 12. Experimental setup for grid interactive inverter

Conclusions

The proposed scheme for a novel grid interactive inverter configuration for power conversion in a solar PV system is found to work satisfactorily. In the scheme THD of the line current is reduced to a large extent by careful selection of the switching angle and operating the inverter in discontinuous conduction mode. Moreover, the proposed scheme utilizes only two thyristors instead of four (of conventional full-bridge inverter) and dispenses with a bulky dc choke. It reduces the overall cost of the inverter.

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